Electrode Placement Strategies for EIT

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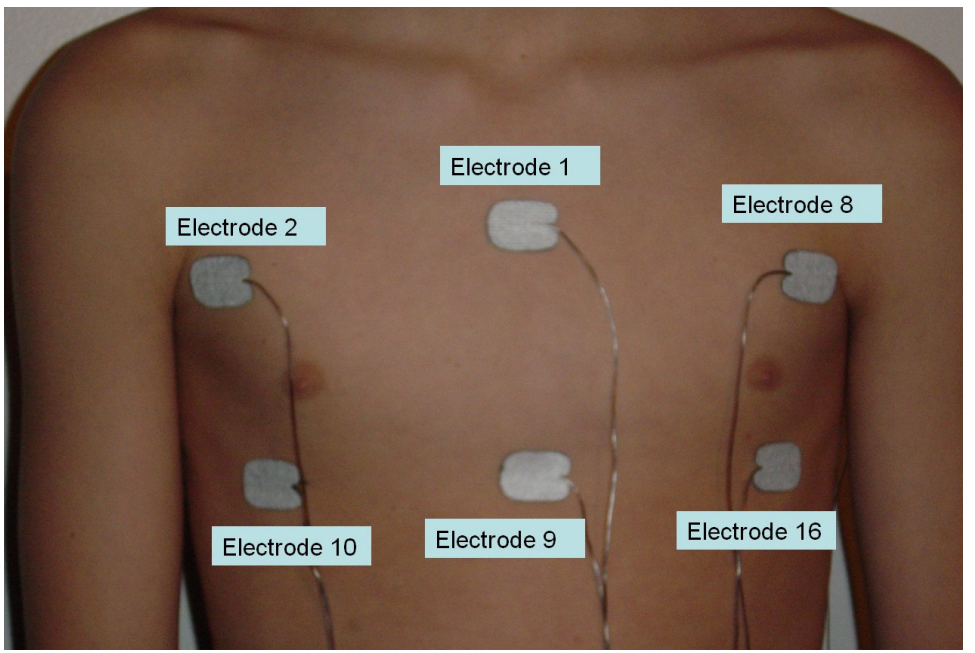
17 Aug 2006

Goal of this work

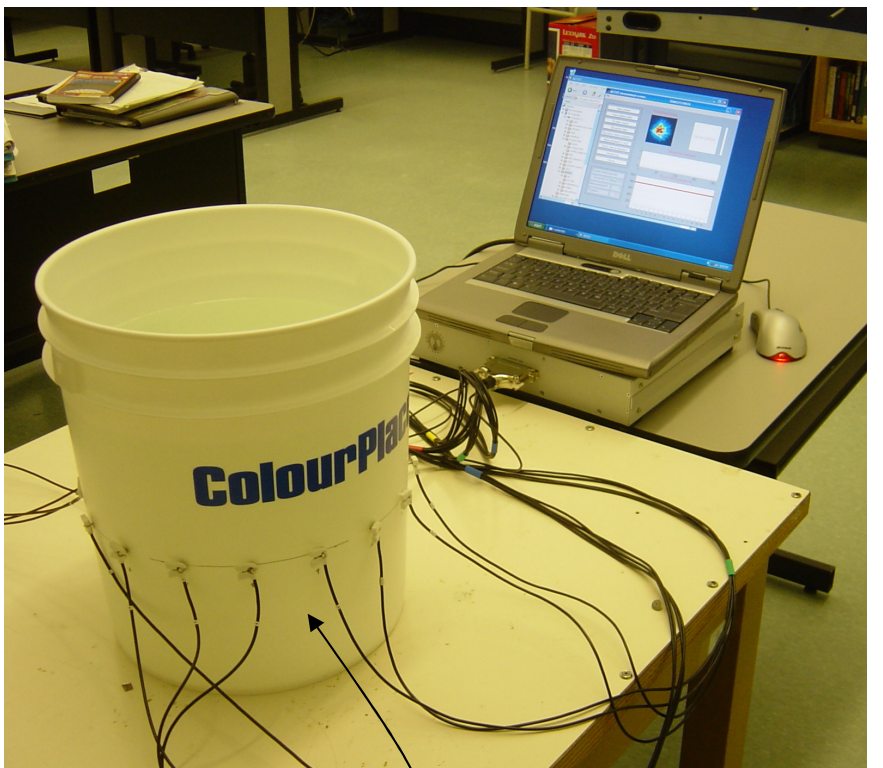
- Many ways to place electrodes in 3D

- How much difference do the variations make with repsect to performance?
- What is most important factor?
- Is any EP Strategey clearly superior to the others?



Constraints

- Desire to validate simulated results with available equipment
  - GOE MF II Type Tomography System
  - 16 Electrode machine intended for 2D planar arrangement with adjacent drive protocol



2D Planar Arrangement

Reconstruction Algorithm

difference image

measurements

$$x = (H^T W H + \lambda^2 R)^{-1} H^T W z$$

R is diag ($H^T H$), the prior used in NOSER[3]

λ is selected with *BestRes*[1]

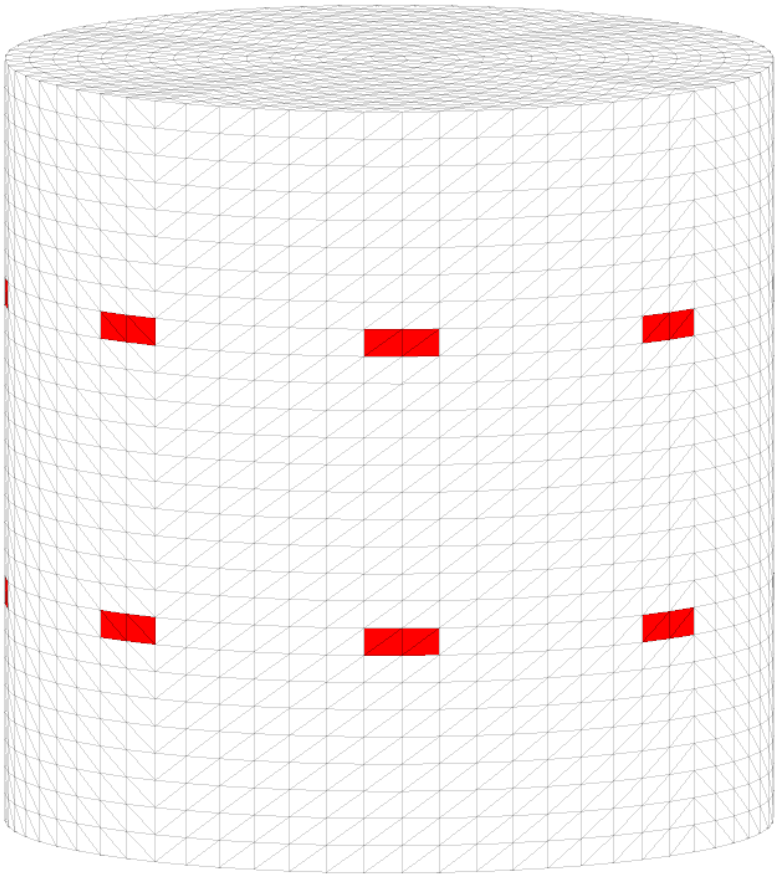
W models the system noise[1,] we assume that all measurements have equal noise variance

x and H are in a nodal basis

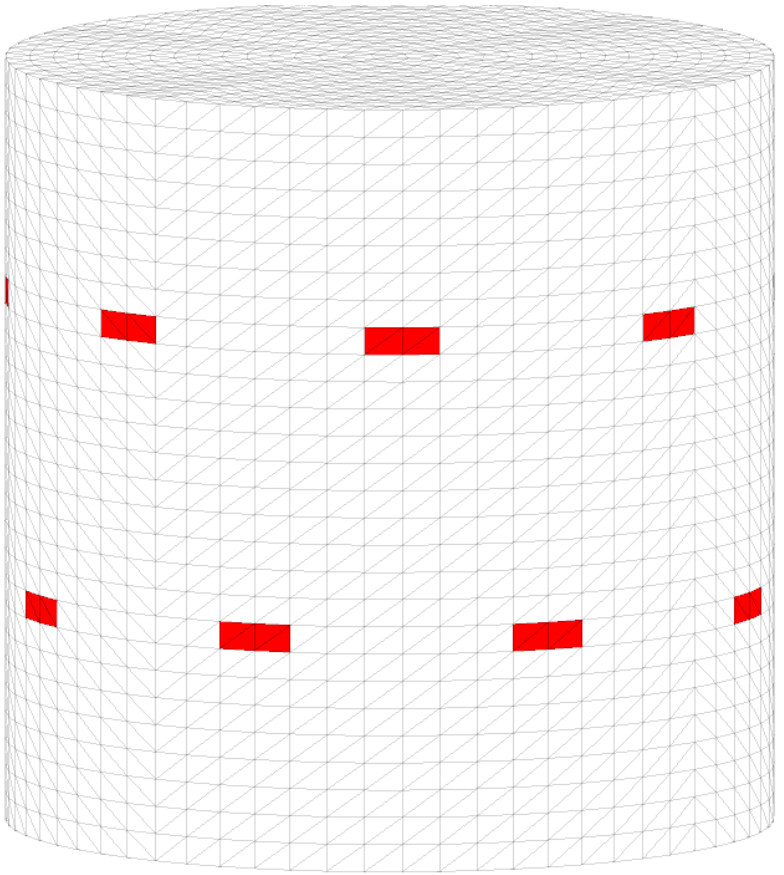
Model is solved using the Nodal Inverse Solver of [5]

z is difference data

2 Electrode Arrangements



Aligned

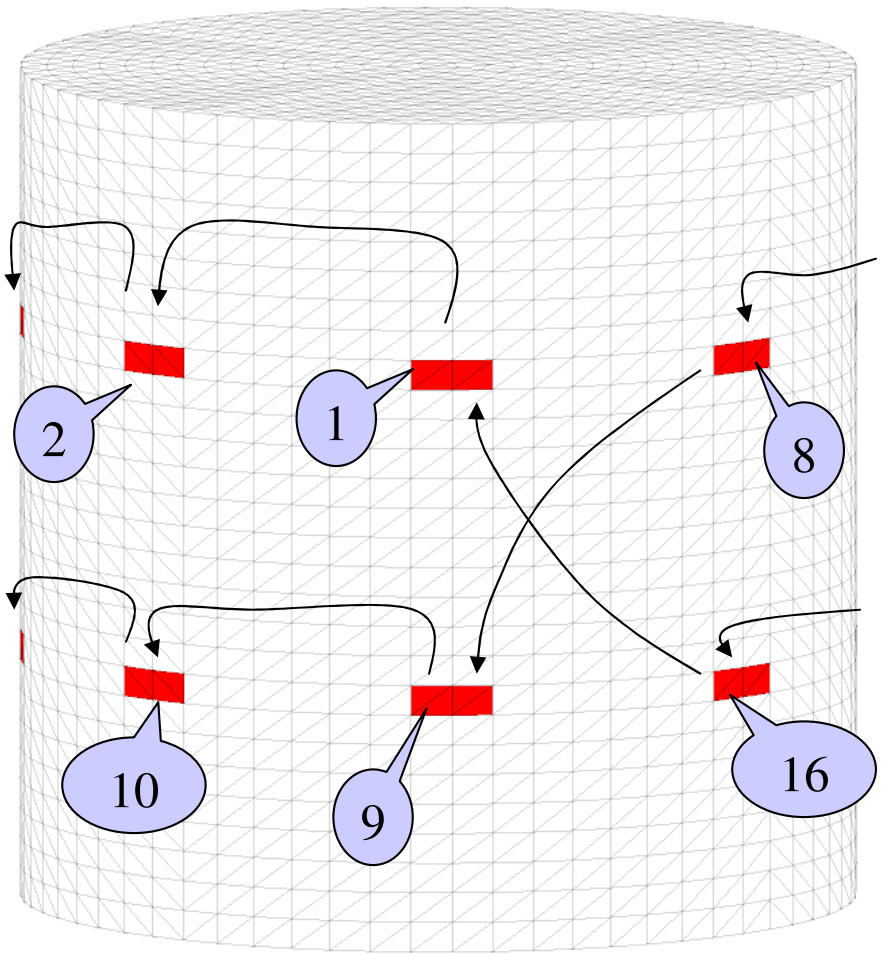


Offset

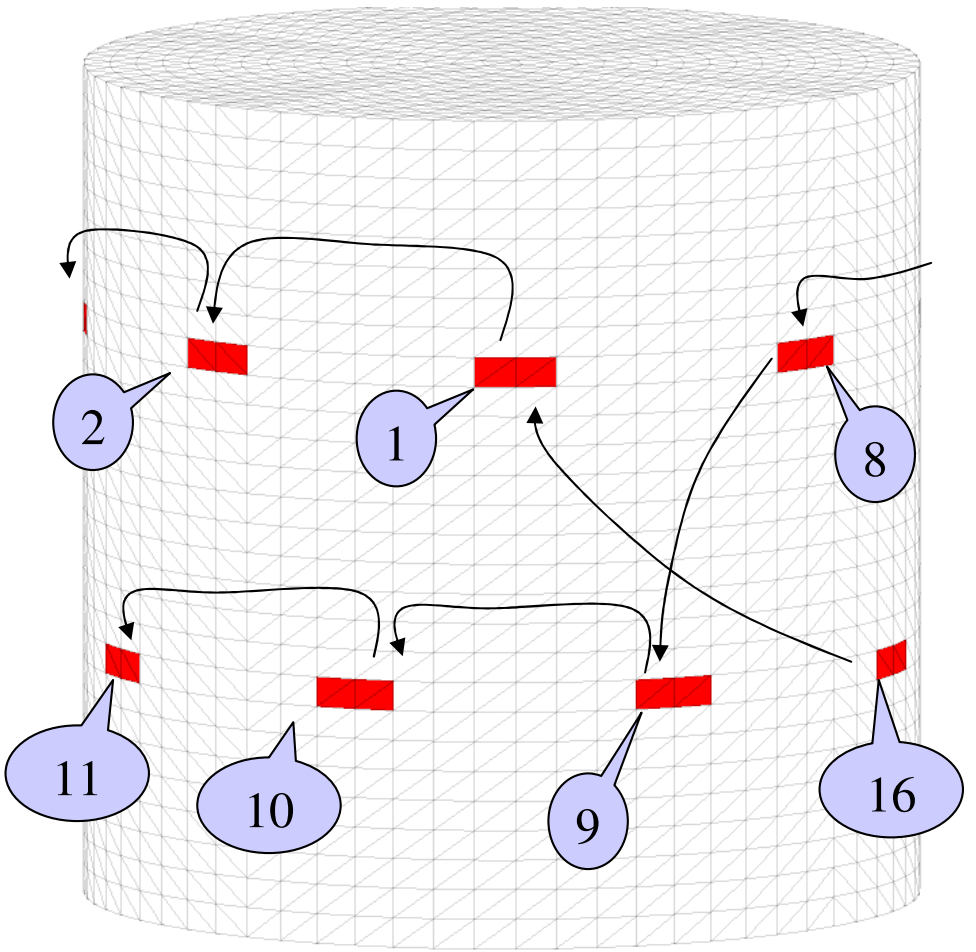
Electrode Sequencing

- The 2 arrangements combined with sequencing gave us 7 EP strategies to evaluate
  - Planar
  - Planar-Offset
  - Planar-Opposite
  - Zigzag
  - Zigzag-Offset
  - Zigzag-Opposite
  - Square

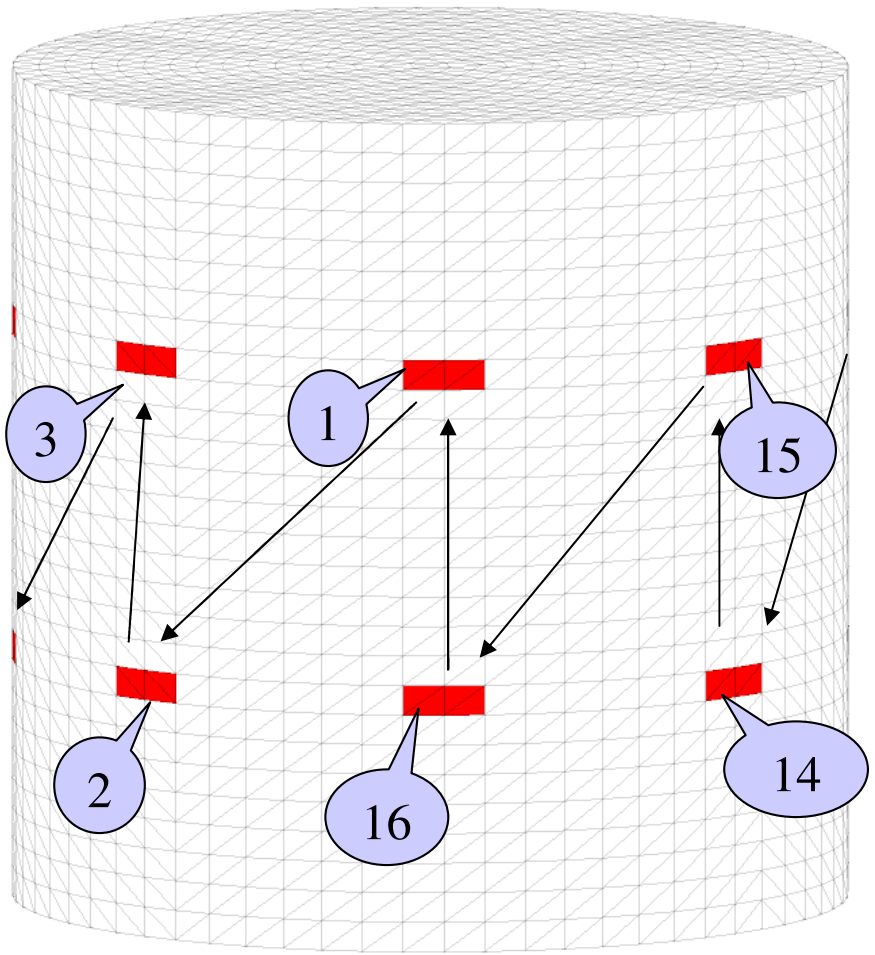
Planar



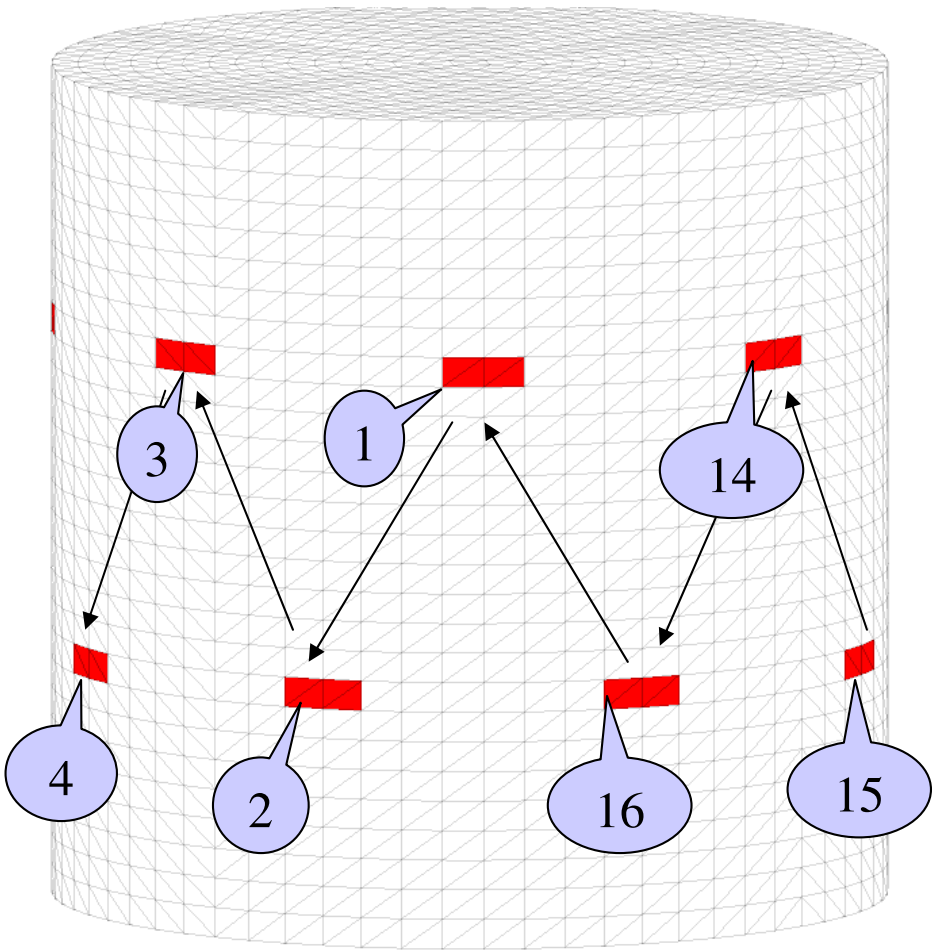
Planar-Offset



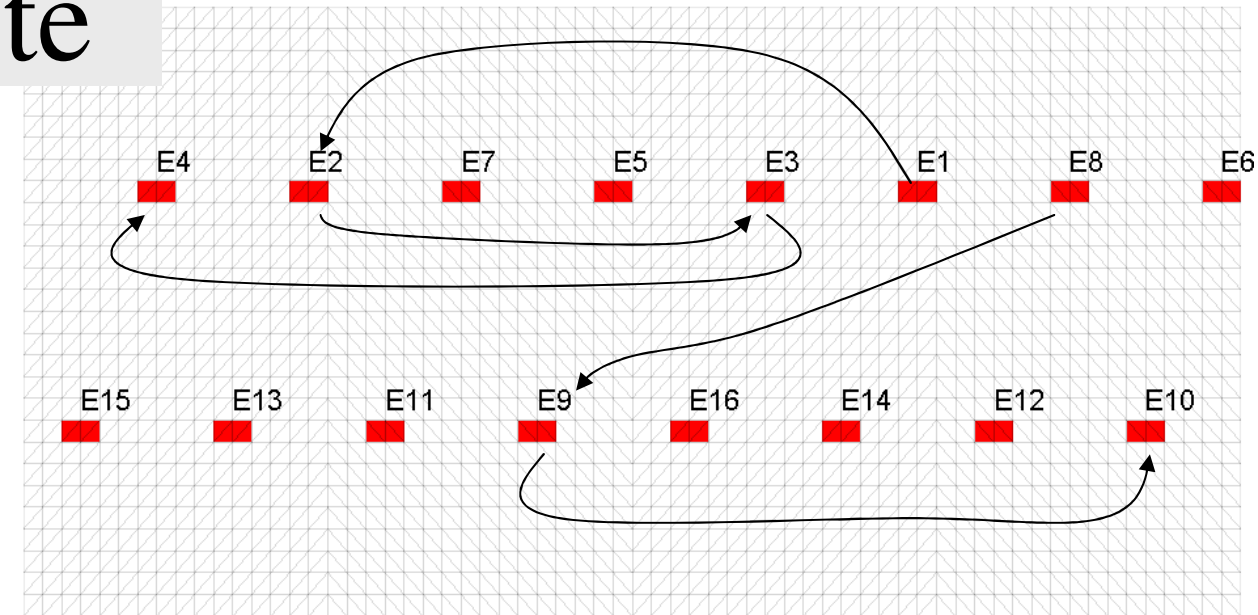
Zigzag



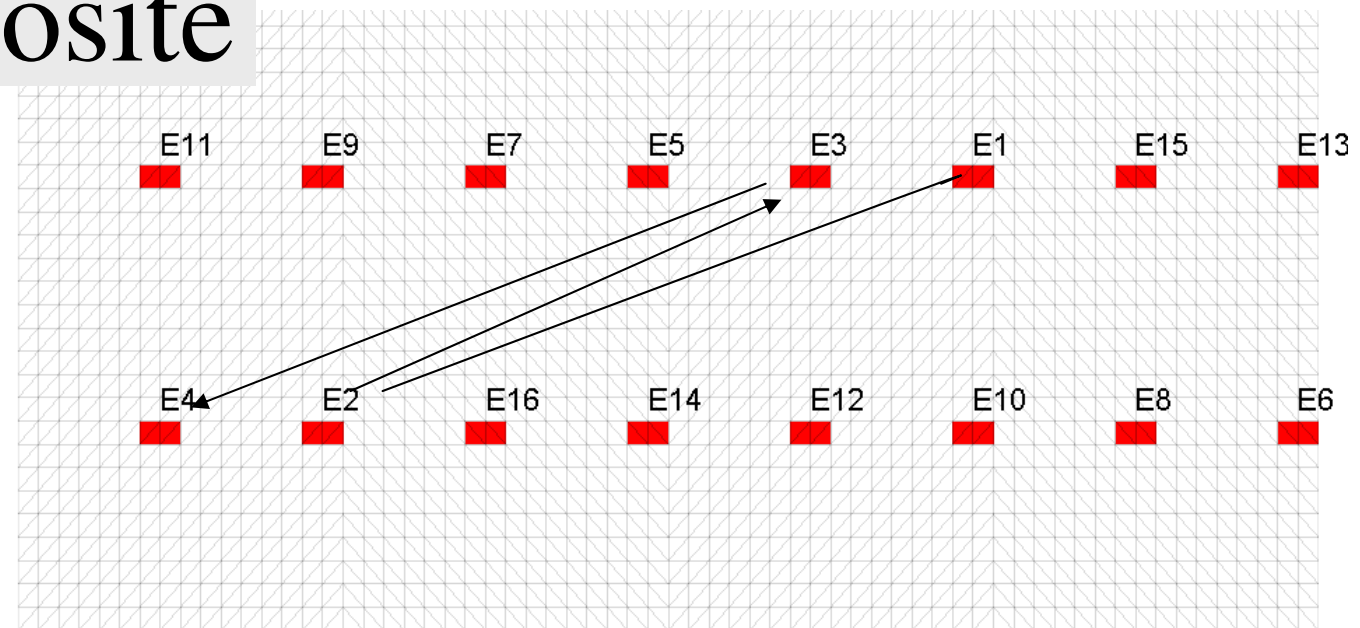
Zigzag-Offset



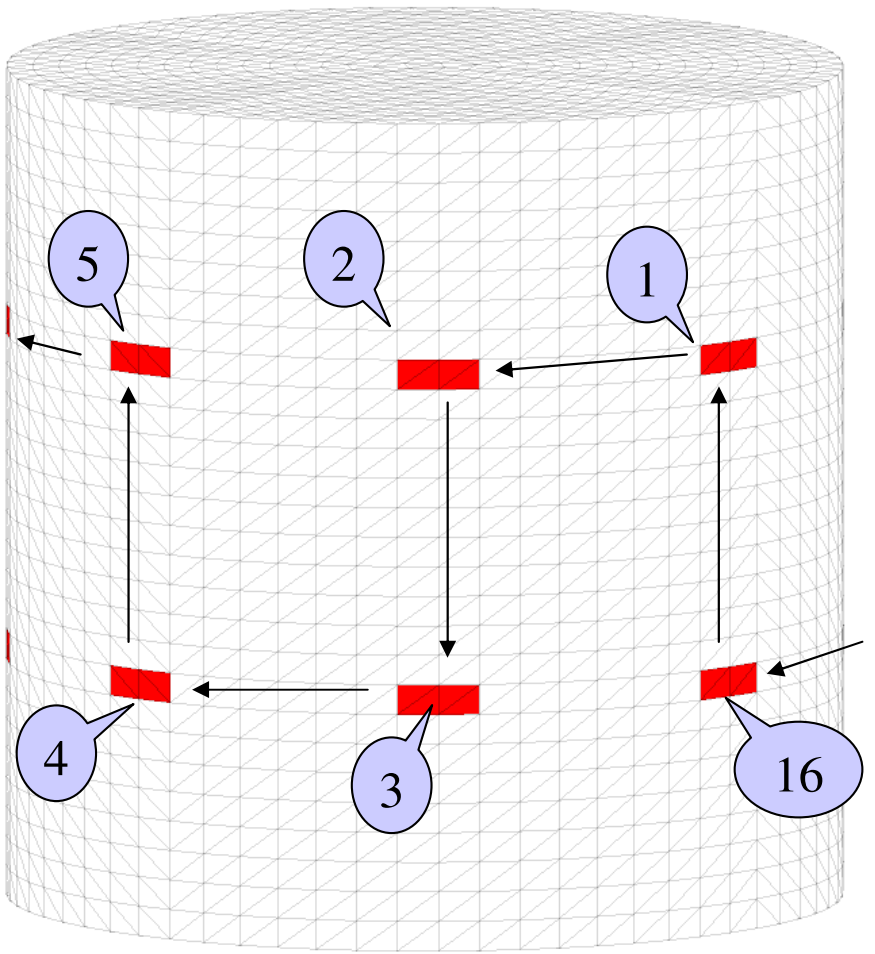
Planar-Opposite



ZigZag-Opposite



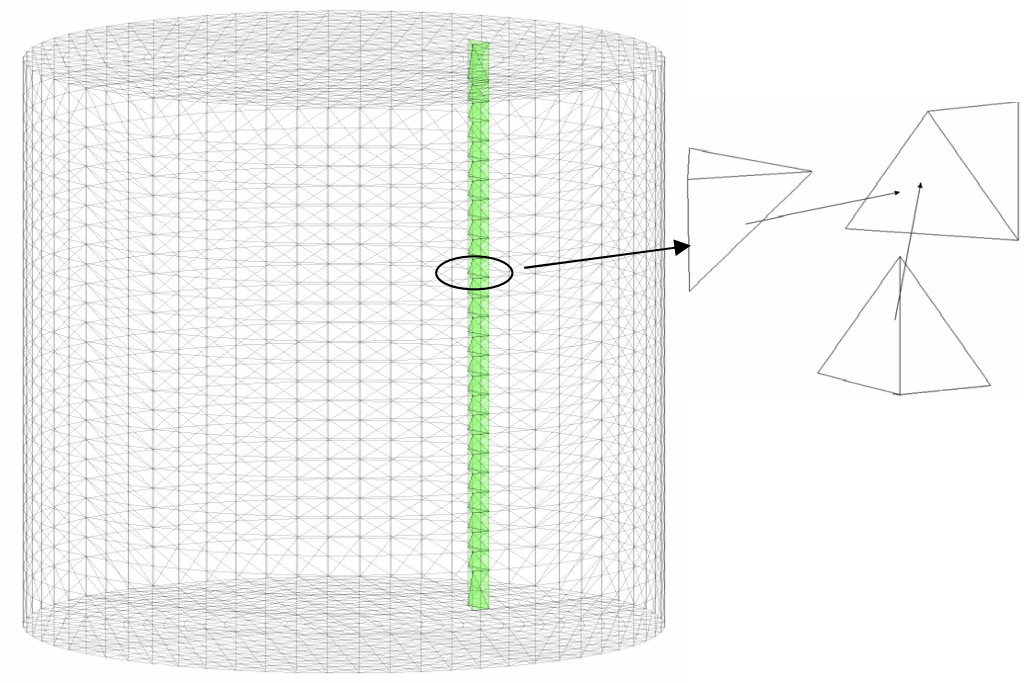
Square



Simulated Data

- Impulse Contrast located at r/2 and moved through 28 vertical locations

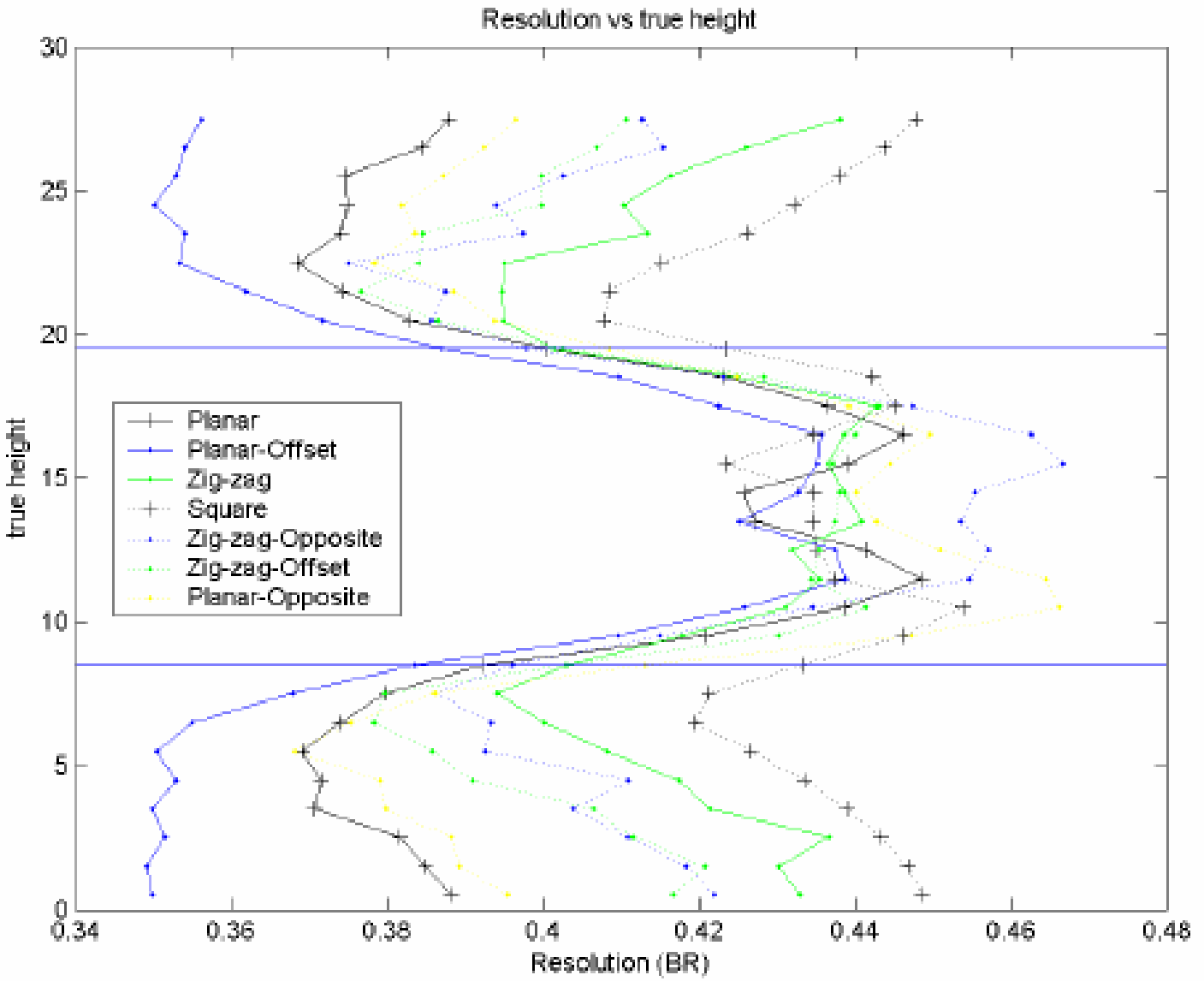
- Led to 28 reconstructions per EP Strat



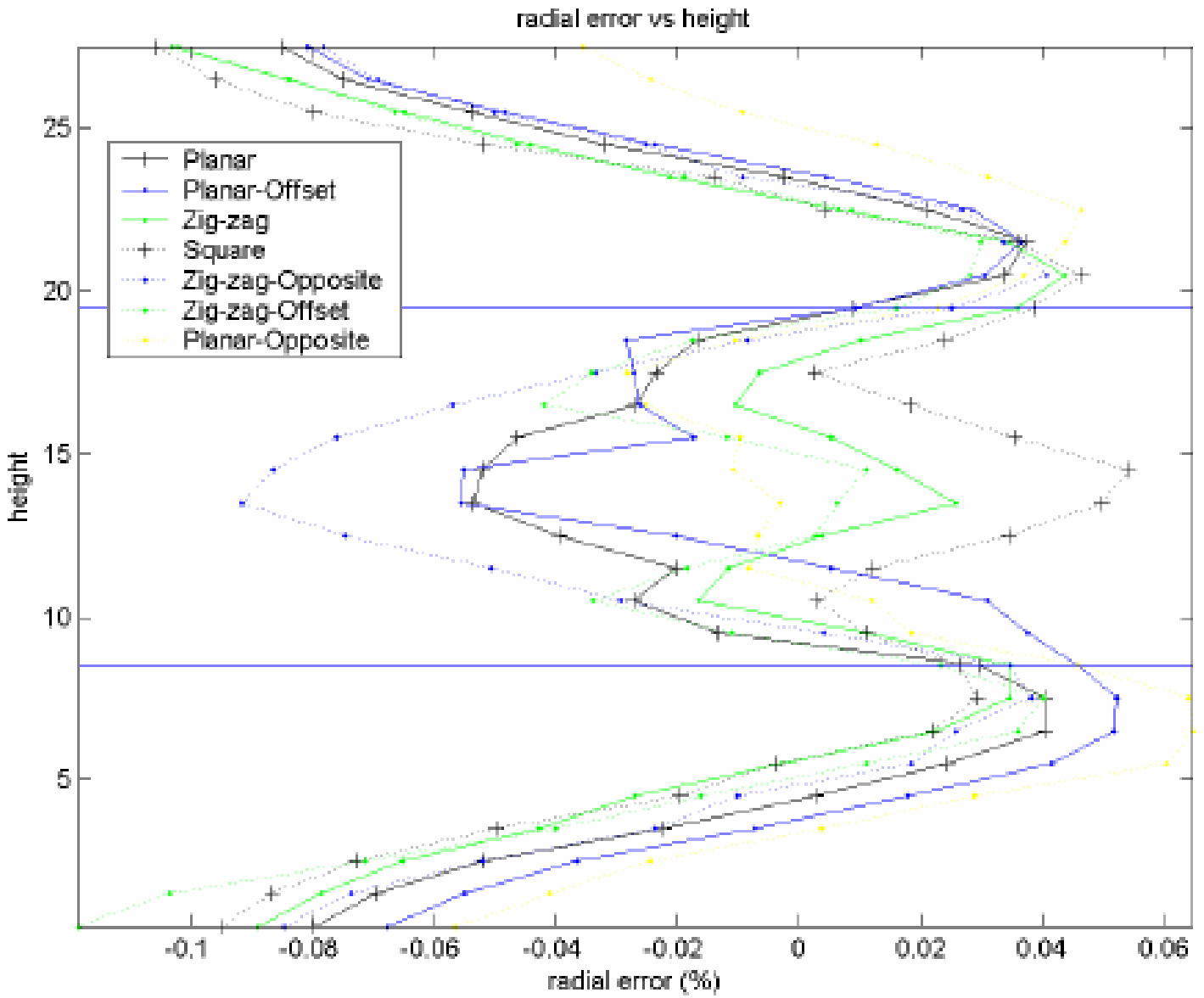
Eval Criteria

- Resolution
- Radial Position Error (PE)
- Vertical PE
- Image Power
- Qualitative (artefacts)
- Immunity to Noise
- Imunity to systematic Electrode Placement Errors
  - Offset Error
  - Layer Separation Error

Resolution – no noise



Radial PE – no noise



Vertical PE – no noise

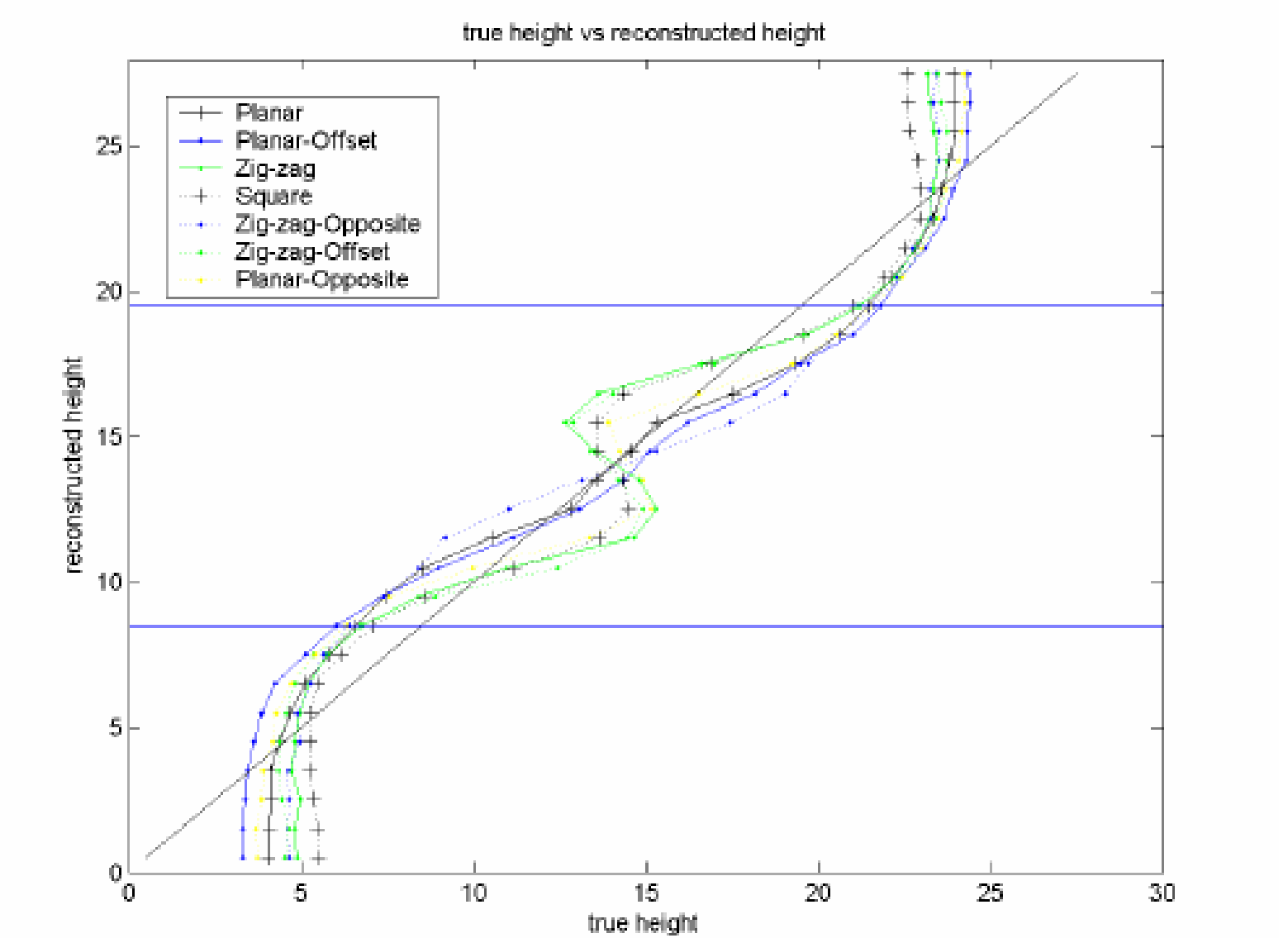
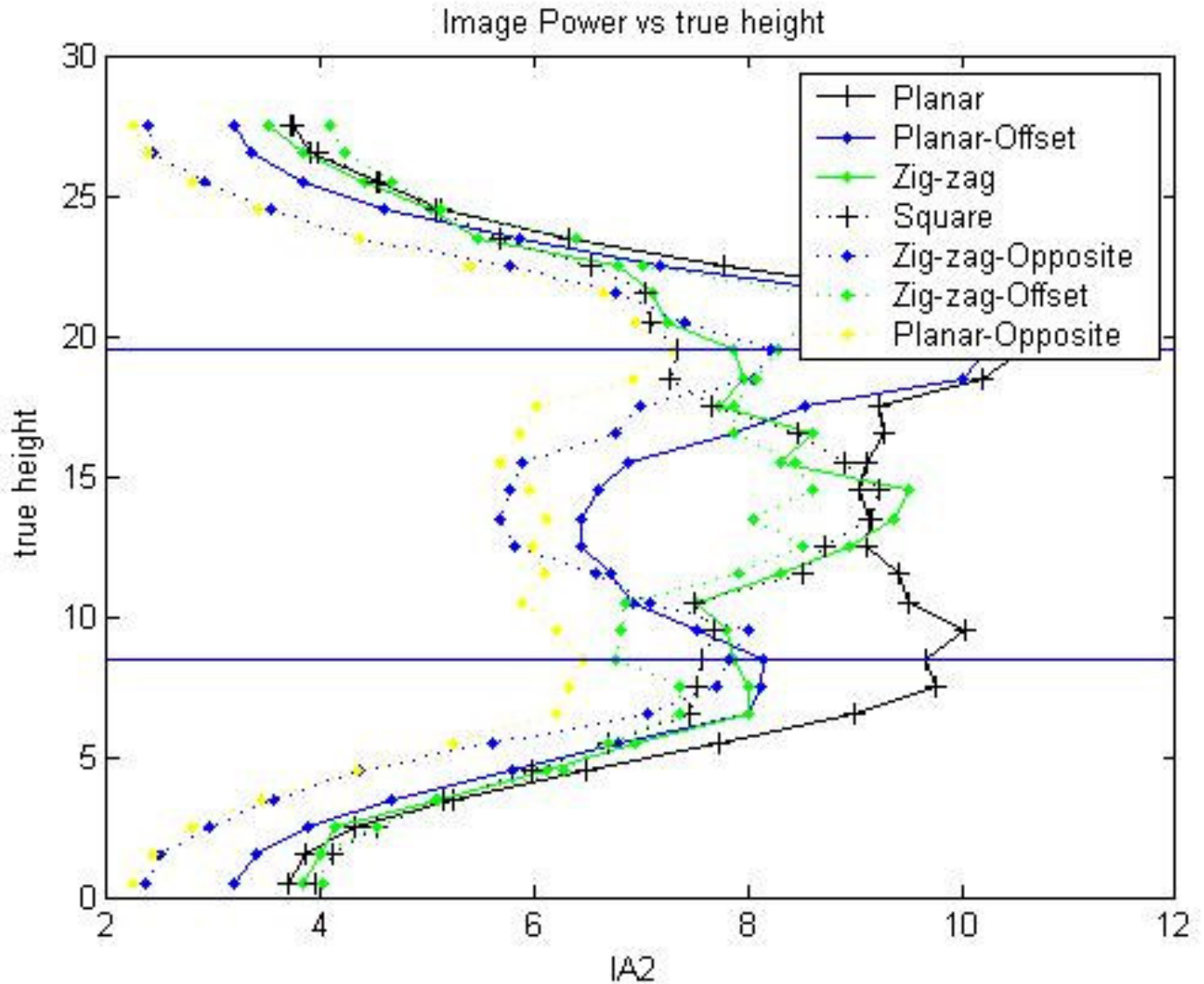


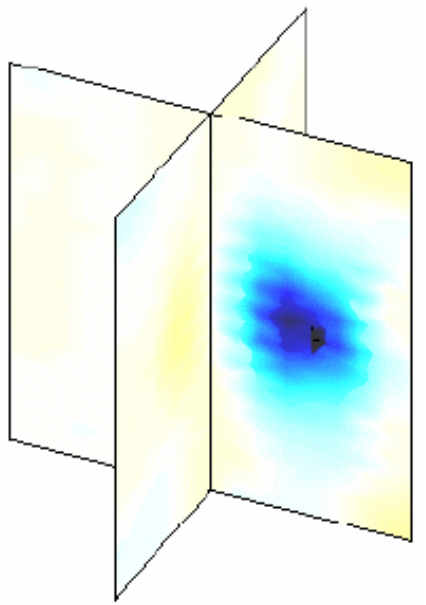
Image Power– no noise



Qualitative Evaluation -1

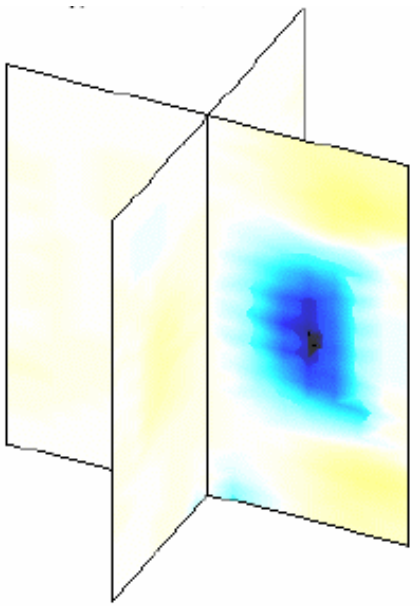
- Planar
- Planar-Opposite
- Planar-Offset
- Square

- Sperical Shaped reconstruction



Qualitative Evaluation -2

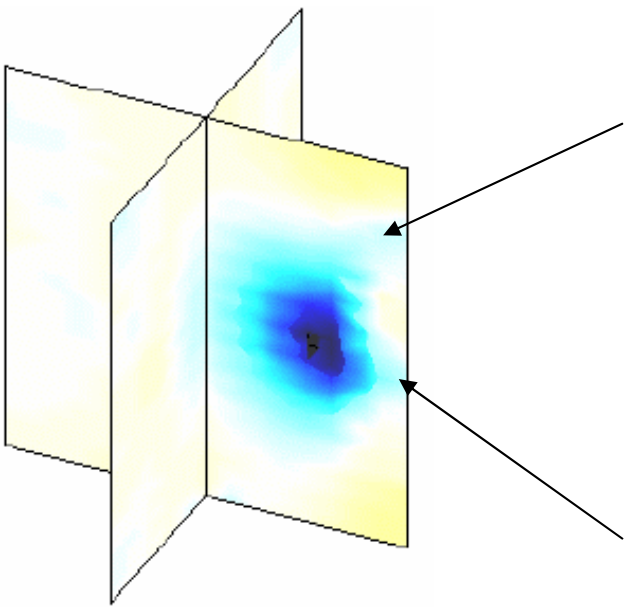
- Zigzag
- Vertically elongated shape



Qualitative Evaluation -3

- Zigzag-Opposite

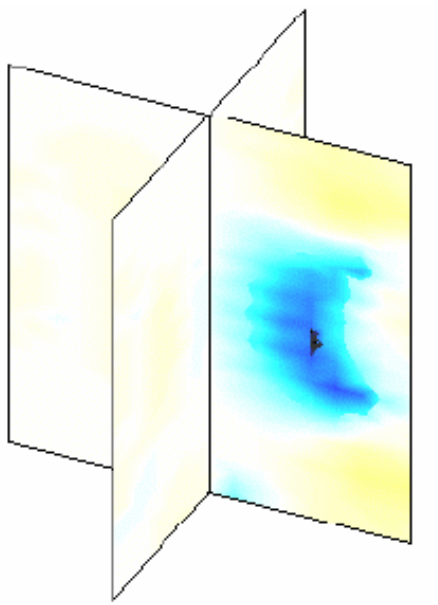
- Artefacts reaching to electrodes



Qualitative Evaluation -4

- Zigzag-Offset

- Bannana shaped artefact

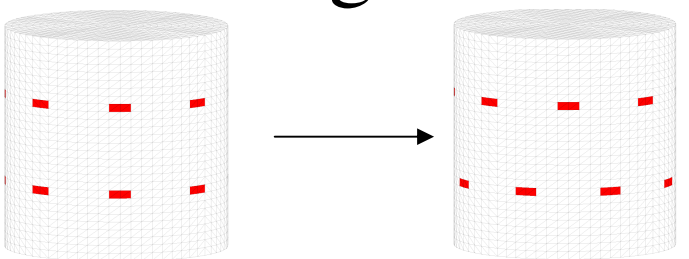


Results - Noise

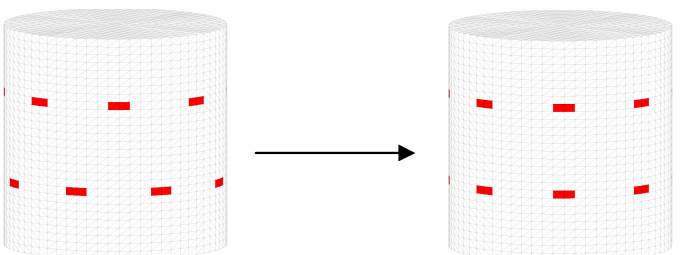
- AWGN Added in 6 steps from 0.1 to 0.6%
- Zigzag, Zigzag-offset failed for noise>0.2%
- Square failed for noise>0.3%
- The 2 Opposite EP Strategies worked up to 0.6% but with degraded resolution and PE
- Planar, Planar-Offset very robust to noise
  - performance degraded slowly

Offset Error

- Data simulated with aligned arangement, reconstructed using offset arrangement



- Data simulated with offset arangement, reconstructed using aligned arrangement

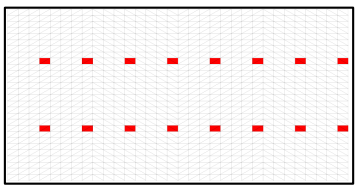


Results – Offset Error

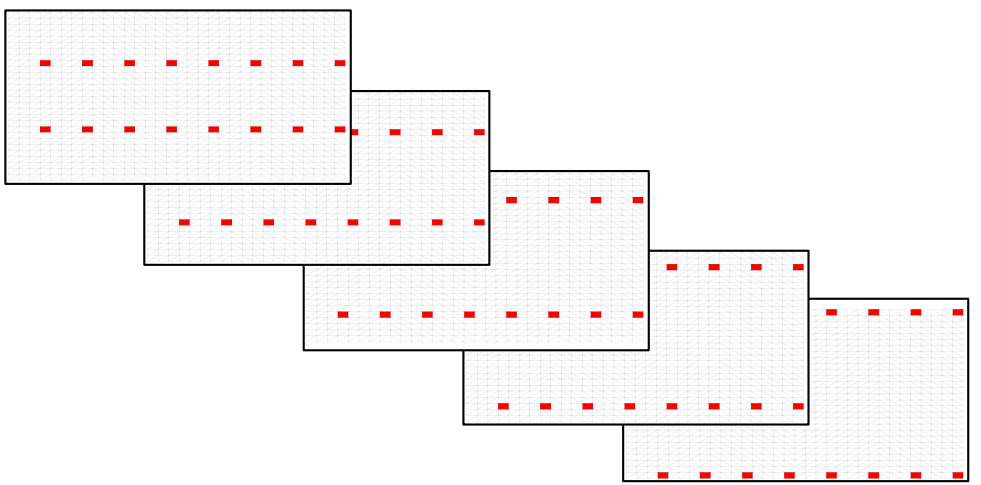
- All strategies showed degraded resolution with Zigzag-Opposite being worst
- Planar-Opposite: conductivity increases were reconstructed as conductivity decreases
- Planar, Planar-Offset, Zigzag all produced good images without shape artefacts
  - …all were rotated in position by about 20 deg

Layer Separation Error

- Data was reconstructed with electrode planes 11 cm apart



- Data was simulated with electrode planes separation from 11cm to 20cm in 9 steps



Results -Layer Separation Error

- Radial PE, Vertical PE and Image power not significantly affected
- All strategies produced vertical elongation artefacts
- Square and opposites most affected
- Zigzag, Zigzag-offset less so
- Planar, Planar-Offset least affected

Significant Observations

- Made many observations; here we cover the important ones
- Planar produces largest signal, most spherical image (least artefacts) for contrasts in the middle section
- Most robust to noise
- Robust to Layer Sep error and Offset error

Summary

	Res	VPE	RPE	Qual	Noise	Offset Error	Layer Sep Error
Planar				+	+	+	+
Planar-Offset				+	+	+	+
Planar-Opposite	-			+		--	--
Zigzag		--		-	--	+	-
Zigzag-Offset		--		--	--	-	-
Zigzag-Opposite	-			-			--
Square		--		+	-		--

Conclusion

- Planar and Planar-offset strategies are the most robust to noise and systematic electrode errors
- *in vivo* placement may be most important issue
- We recommend the Planar EP Strategy

Recommended 3D electrode placement